Stature Estimation in White South African Females

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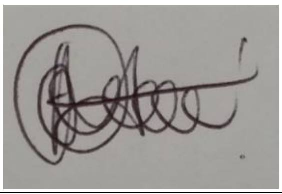
Declaration

I, Michelle H. Cloete, declare that this dissertation is my own work. It is being submitted for the Degree of Master of Science in Medicine at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.



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Signed on this day 26 of March 2018, Braamfontein.

Abstract

Methods of stature estimation have been studied by many researchers to determine the height of an unknown individual from their skeletal remains. Stature is most accurately estimated using the anatomical method. This method has, however, been called into question by different researchers due to population specificity, secular trends and the use of inaccurate soft tissue correction factors. MRI scans, taken at the Wits Donald Gordon Medical Centre, Radiology Department were used to assess the accuracy of the anatomical method for White South African females. The skeletal elements contributing to stature were then measured using OsiriX in order to calculate total skeletal height (TSH). Pearson's correlation indicated that there was a strong and positive linear relationship between TSH and living stature. A paired t-test was used to assess the accuracy of the anatomical method and the soft tissue correction factor used. The paired t-test indicated that the Fully's (1956) soft tissue correction factor, and the equation of Raxter and colleagues (2006) significantly underestimated stature by 7.1 cm and 6.1 cm respectively. Bidmos and Manger's (2012) equation overestimates stature significantly by 8.89 cm. Brits and colleagues (2017) equation overestimated stature by a non-significant amount of 0.04 cm. In an attempt to further increase the accuracy of the anatomical method for White South Africans, a new soft tissue correction factor and equation were created.

<u>**Quote:**</u>

"You are not judged by the height you have risen, but from the depth you have climbed"

– Frederick Douglas

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1. Introduction

Stature is the measurement of an individual's height. Stature estimation is one of four biological indicators, along with age, sex and population affinity, used in the process of identifying an individual (Dirkmaat & Cabo, 2012). Stature estimation is completed for forensic, archaeological (Bidmos & Asala, 2005; Dirkmaat & Cabo, 2012; Christensen *et al.,* 2014; Cardoso *et al.,* 2015; Sládek *et al.,* 2015; Jeong & Jantz, 2016). The 19th century saw a rise in scientific studies of stature (Steckel, 2004). The accurate estimation of stature is very important to help categorize an individual as either short, medium or tall during the identification process. This is important as few people are aware of their own exact height or that of friends or family (Steyn & Smith, 2007). Furthermore, this categorization of an individual into short, medium or tall provides invaluable information in terms of decreasing the number of possible unknown deceased individuals and, along with the other biological indicators, provides the first limitation for identification (Kimmerle *et al.,* 2008; Krishan *et al.,* 2012). Stature is considered one of the main methods for describing body size and is also used to calculate the body mass index (Sorkin *et al.,* 1999). Stature also provides valuable information regarding temporal trends in body size, sexual dimorphism and overall health and nutrition of populations in archaeological and paleontological studies (Sorkin *et al.,* 1999; Raxter *et al.,* 2006; Ruff *et al.,* 2012; Niskanen *et al.,* 2013).

There are a number of ways to estimate stature from skeletal remains. These methods include the mathematical and the anatomical methods. The mathematical method comprises use of regression formulae (Raxter *et al.,* 2006) and bone stature ratios (Sjøvold, 2000). The anatomical method uses the sum of all the skeletal elements contributing towards stature along with a soft tissue correction factor and as such is considered the most accurate stature estimation method (Raxter *et al.*, 2006; Bidmos & Manger, 2012). Research has been conducted on the estimation of stature of Black South Africans. This research, along with other studies, has shown that there are large inaccuracies of the soft tissue correction factor used in the anatomical method (Raxter *et al.,* 2006; Bidmos & Manger, 2012; Brits *et al*., 2017). To date, there is no information pertaining to stature estimations and the inaccuracies of the soft tissue correction factor for White South Africans. The aim of this research was therefore to assess the accuracy of the various soft tissue correction factors through the use of MRI scans for White South African females. If the soft tissue correction factors are found to be inaccurate, a new soft tissue correction factor will be calculated.

2. Literature Review

2.1. Stature

The estimation of stature is considered to be more straightforward compared to the assessment of other biological parameters. This is because the skeletal remains are measured and either a regression formula is used or an equation adding in the soft tissue correction factor (Cardoso *et al.,* 2015). Estimating stature becomes more complicated when choosing the correct formula to use based on sex, population specific equations and choosing the appropriate bone to measure (Cardoso *et al*., 2015).

There are three main descriptions of stature that may be useful in accurately identifying an individual from their skeletal remains. These include living stature, forensic stature and cadaveric stature (Giroux & Wescott, 2008; Cardoso *et al.*, 2015). Living stature or measured stature can be defined as the stature (height) of a living person when standing in the standardised position; standing upright with the head facing forward in a comfortable manner. The individual's height is measured using either an anthropometer or stadiometer (Cardoso *et al.,* 2015).

Forensic stature is the stature that appears on all government documentation including driver licenses, passports and identity documents. This may be self-reported stature (Cardoso *et al.,* 2015). It should, however, be noted that individuals often underestimate or overestimate their own stature (Steyn & Smith, 2007). The individual's stature may also be measured before it is reported on the government issued documentation. It is important to note however, that the stature that appears on these documents may not actually reflect an individual's actual living stature (Cardoso *et al.,* 2015). An example of this could be due to the use of uncalibrated equipment. As a result the actual living stature of the individual is not reflected in the reported forensic stature (Cardoso *et al.,* 2015).

Cadaveric stature is the height directly measured from a corpse, while living stature is measured from a living individual (Giroux & Wescott, 2008). Cadaveric stature has previously contained many errors due to different measurement techniques being used (Christensen *et al.,* 2014). For example, some researchers measured cadaveric stature while the cadaver was in the supine position on a table, while other researchers measured the cadaveric stature in a standing position on an upright table (Maijanen, 2009). In some collections cadaveric stature has been measured with a probe placed in the ears of cadavers to ensure an upright "standing position" (Cardoso *et al*., 2015). Stature, for cadavers from the Terry Collection, was measured with extended knees, a curved vertebral column and the head in the Frankfurt horizontal plane (Trotter & Gleser, 1958; Albanese *et al.,* 2016). Because of the considered accurate measurements of stature of the Terry collection, this skeletal reference collection has been used by many researchers as a reference sample when estimating stature (Trotter & Gleser, 1952; Trotter & Gleser, 1958; Byers *et al.,* 1989; Prasad *et al.,* 1996; Konigsberg *et al.,* 1998; Mays, 2016).

2.2. Stature estimation

2.2.1. Mathematical method

The mathematical method uses a set of regression formulae derived from the measurements of single or multiple bones as well as bone/stature ratios. This method can be used when there is an incomplete skeleton or when the skeletal remains are fragmented (Adams *et al.,* 2009; Ruff *et al.,* 2012). The mathematical method, whether it involves the use of regression equations or bone/stature ratios, is relatively quick and easy to use (Béguelin, 2011).

2.2.1.1. Regression equations

The mathematical method assumes that the individual's stature is similar to that of the reference population used to produce the equations (Ruff *et al.,* 2012; Mays, 2016). Differences in stature can be due to geographic, genetic and/or cultural factors (Ruff *et al.,* 2012). This is as a result of secular changes which will be discussed later (2.3.3. Secular trends and population specificity, page 14). Secular changes are important factors to take into account as using the wrong equation will bias the results (Ruff *et al.,* 2012). As such, the appropriate reference sample is one of three factors that influence the accuracy of the mathematical method. The other two factors include the bone dimensions and the regression model used (Jeong & Jantz, 2016).

Pearson's (1899) research created the basis for regression analyses used today to derive stature estimation equations (as cited by Trotter & Gleser, 1952; Lundy 1985; Albanese *et al.*, 2016). Furthermore, Pearson's (1899) contribution was invaluable to the field of forensic science as he was the first to produce regression equations for stature estimation from long bone measurements (Hauser *et al.*, 2005; Krishan *et al.*, 2012). Pearson (1899) did observe that his reconstructions of stature were not universally applicable for all population groups because of differentiating body proportions (Trotter & Gleser, 1952; Hauser *et al.*, 2005.).

Trotter and Gleser (1952) derived linear stature estimation regression equations from long bones for American populations. As a result of their accuracy these equations are the most widely used equations for the estimation of stature and they are considered the benchmark used to create new equations (Trotter & Gleser, 1952; Raxter *et al.*, 2006; Dayal *et al.*, 2008; Kimmerle *et al.*, 2008; Didia *et al.*, 2009; Albanese *et al.*, 2016).

The accuracy of the equations by Trotter and Gleser (1952), have however been called into question by many researchers, including themselves (Trotter & Gleser, 1958; Lundy, 1985; Muñoz *et al.*, 2001). For this reason Trotter and Gleser (1958) revaluated the accuracy of their equations by studying various American populations including White, Black, Asian, Native American and Latin American individuals from the Korean War. The military personnel research showed that there are significant differences in height proportions between each population group (Trotter & Gleser, 1958; Hauser *et al.*, 2005). In addition, they observed an error in the equations used for the White population - possibly due to inter-observer bias in measuring techniques, variation between moist and dry bones (as there is a 2 mm difference) and a change in the relationship of long bone length and stature (Trotter & Gleser, 1958). The accuracy of the equations however, was not assessed. This was because the population sample was too small and could not be used for comparison with other population groups. It was, however ascertained that different equations need to be derived for different population groups (Trotter & Gleser, 1958).

It is often the case that many regression formulae do underestimate tall individuals, while overestimating short individuals (Sjøvold, 2000).

Regression formulae have been deduced to estimate stature from many different skeletal components, such as the femur (Lundy & Feldesman, 1987; Muñoz *et al.*, 2001; Dayal *et al.*, 2008), tibia (Muñoz *et al.*, 2001; Duyar & Pelin, 2003; Dayal *et al.*, 2008), ulna (Duyar & Pelin, 2003) and calcaneus (Bidmos & Manger, 2005), to name but a few. Regression formulae have been derived from numerous bones representing a plethora of population groups including, Nigerians (Didia *et al*., 2009), Black South Africans (Bidmos & Asala, 2005; Dayal *et al*., 2008), Americans (Trotter and Gleser, 1952; Giroux & Wescott, 2008), Turks (Özaslan *et al.*, 2003), Rajputs from North India (Krishan & Sharma, 2007) and Spanish (Muñoz *et al.*, 2001). Although different skeletal elements have been used for stature estimation, the long bones of individuals are the most important to use for stature estimation as these are the bones that directly contribute towards stature. Long bones are also the most likely skeletal elements to remain after many years post-mortem (Prasad *et al*., 1996; Sjøvold 2000; Raxter *et al.*, 2006; Giurazza *et al.*, 2012).

Fragmentary and short bones can also be used to estimate stature (Byers *et al.*, 1989). This is especially the case when a body has been dismembered or the bones are badly damaged (Prasad *et al.*, 1996). One of the main disadvantages of this procedure is that estimating stature from these bones provides greater errors than using long bones (Byers *et al.*, 1989). This often takes place when calculating the length of the long bone from the bone fragments to then be used to calculate stature (Prasad *et al.*, 1996).

Further accuracy of the equations may be increased through multivariate equations (Albanese *et al*., 2016). Statistically multiple bones provide a better fit for the regression equations. This is because irregular limb segments can be potentially minimized. In addition, the multivariate equation can provide a better range of stature (Albanese *et al*., 2016). Trotter and Gleser (1952, 1958) created multiple regression equations for the upper or lower limb bones and as a result observed that the use of multiple regression equations increases accuracy marginally.

The tibia and other distal limb elements are sensitive to factors that may influence a change in proportion when compared to stature. This is the case when the tibia and fibula are compared to the trunk and proximal limbs of an individual in terms of body proportions. Variations in the femur, however, have not been observed. As such the femur, when used in equations, provides the best stature estimates with minimal errors (Albanese *et al.*, 2016; Mays, 2016). Trotter & Gleser (1958) further questioned the use of the tibia for estimating stature. This could produce a difference of 2cm in stature estimates.

2.2.1.2. Bone stature ratios

Previous research has identified that there is a relationship between a single bone, such as the femur, or multiple bones, and stature (Sjøvold 2000). The femur has the highest correlation to stature of any skeletal component, and thus is more accurate for stature ratios (Béguelin, 2011). This has allowed for stature ratios to give reasonable and very accurate stature estimations (Feldesman *et al*., 1990). This is only the case however, for specific population and sex groups for which the regression equations have been created (Feldesman *et al*., 1990). Sjøvold (1990) created a "line of organic correlation" which encompasses both population and sex into a neutral major axis regression equation from specific long bones (i.e. the femur). As has been observed throughout the use of femur/stature ratios, the "line of organic correlation" also tends to overestimate stature for taller individuals, while it underestimates stature for shorter individuals (Sjøvold 2000).

Feldesman and colleague's work (1990) on stature estimation using bone/stature ratios, they differentiated between three population groups: Black, White and Asian. They found that there were no main differences between sex or between the White and Asian population groups. Alternatively, the Black population group was vastly different (Feldesman *et al.*, 1990; Feldesman & Fountain, 1996). As a result, Ruff and colleagues (2012) criticised this research (Feldesman & Fountain, 1996) and have suggested that the observed population differences were possibly due to differences in climatic regions as opposed to temporal variations in stature estimations. In order to account for these differences the use of sex and population specific ratios should be used instead of generic ratios. This will in turn increase the accuracy of estimating stature for unknown individuals (Feldesman & Fountain, 1996).

2.2.2. Anatomical method

The anatomical method involves an estimation of stature based on the sum of the measurements of the major components that contribute directly to stature; i.e. the cranium, vertebrae, femur, tibia and ankle height. To this a universally applicable soft tissue correction factor is added. Due to the inclusion of all the bones that contribute directly towards stature, this method has been described as the most accurate stature estimation method and as a result the anatomical method has been applied by many researchers (Feldesman & Fountain, 1996; Bidmos, 2005; Bidmos & Asala, 2005; Raxter *et al.*, 2006; Maijanen, 2009; Bidmos & Manger, 2012; Christensen *et al.*, 2014; Brits *et al.*, 2017). This is because including all the skeletal elements that contribute directly to stature also incorporates irregular body proportions (Maijanen, 2009). The application of this method is however, dependent on the availability of complete skeletal remains (Feldesman & Fountain, 1996; Raxter *et al.*, 2006; Mays, 2016).

Fully's (1956) anatomical method is based on White French men that were killed during World War II (Raxter *et al.*, 2006). His (1956) anatomical method can be applied regardless of sex and population affinity, unlike regression methods used for stature estimation. Furthermore, Fully's (1956) anatomical method is also the most commonly used form of the anatomical method (Brits *et al*., 2017).

Fully's (1956) anatomical method uses a soft tissue correction factor that is added to total skeletal height in order to estimate stature. The soft tissue correction factor is used to account for the cartilage and skin that is found in the scalp, heel, hip, knee, ankle and intervertebral disks respectively in order to arrive at an accurate living stature estimate (Raxter *et al.,* 2006; Bidmos & Manger, 2012). The soft tissue correction factors he used were 10 cm for an individual with a total skeletal height (TSH) of less or equal to 153.5 cm, 10.5 cm for TSH between 153.6 and 165.4 cm and 11.5 cm for TSH greater or equal to 165.5 cm (Fully, 1956; Raxter *et al.,* 2006; Jeong & Jantz, 2016). This factor however, has been observed to underestimate the stature of other population groups (Bidmos, 2005; Raxter *et al.,* 2006).

Researchers evaluated the accuracy of Fully's (1956) anatomical method, which has resulted in its refinement. King (2004) studied 36 White and Black Americans from the William M. Bass Donated Collection. Fully's technique was observed to estimate a lower stature than the reported cadaveric statures, especially in the Black population (King, 2004). Bidmos (2005) measured 156 White and Black South African skeletons from the Raymond A. Dart Collection of Human Skeletons and came to the same conclusions as King (2004). Bidmos (2005) however did observe that there was a less drastic underestimation of stature of the White South African skeletons. Furthermore, both King (2004) and Bidmos (2005) suggested that Fully's (1956) original soft tissue correction factors were flawed and suggested that might cause the observed errors (underestimation/overestimation of stature).

Raxter and colleagues (2006) studied 119 Black and White males and females from the Terry Collection at the National Museum of Natural History, Smithsonian Institution. Similar to work by King (2004) and Bidmos (2005), they observed that Fully's (1956) technique underestimated stature. Raxter and colleagues (2006) further discerned that the measurements may be the reason for the inaccuracies of the soft tissue correction factors (Raxter *et al*., 2006). As a result, Raxter and colleagues (2006) redefined the measurements of the skeletal elements to be used in order to estimate stature (Raxter *et* al., 2006). This took place as it is imperative to have methods and measuring techniques explained in detail for future researchers to follow in order to avoid misinterpretations of measurements (Didia *et al*., 2009).

Raxter and colleagues (2006) stated that there are "gaps" and "overlaps" in measuring some of the skeletal components. For example, there is an overlap of the distal tibial articular surface and the calcaneus. Thus, this overlap needs to be adjusted. According to Raxter and colleagues (2006), the overlapping skeletal measurements can be adjusted for by the use of a single soft tissue correction factor which is used in a single equation. This will adjust for both overlapping measurements and possibly missing measurements. In addition the distances between the odontoid process and basion, the first sacral vertebra and the acetabular roof, and the curvature of the spine may also cause inaccuracies (Raxter *et al.*, 2006; Mays, 2016).

Raxter and colleagues (2006) concluded that Fully's (1956) technique resulted in an average 2.4 cm underestimation of stature. In response to this underestimation, new soft tissue correction factors were created. This new soft tissue correction factor was calculated to be 12.4 cm. Raxter and colleagues (2006) used a single soft tissue correction factor in an equation rather than Fully's (1956) different soft tissue correction factors identified by total skeletal height. The new soft tissue correction factor created also took into account age, and has provided a residual error of less than 0.1% (Raxter *et al.*, 2006; Auerbach, 2011; Bidmos & Manger, 2012; Jeong & Jantz, 2016).

Bidmos and Manger (2012) studied 28 Black male individuals through the use of Magnetic Resonance Imaging (MRI) scans. Their research was completed on modern living population groups in order to determine whether the soft tissue correction factors suggested by Fully (1956) and Raxter and colleagues (2006) were universally applicable or population specific. They determined that the soft tissue correction factors were not appropriate for Black South African Males. This could be due to population and sex specific soft tissue variation (Bidmos, 2005; Bidmos & Manger, 2012).

Furthermore, the correction factors used by Fully (1956) and Raxter and colleagues (2006) were found to significantly underestimate the living stature of Black South African males by approximately 15.8 cm (Bidmos & Manger, 2012). For this reason the soft tissue correction factors used by Fully (1956) and Raxter and colleagues (2006) cannot be applied to Black South African males, and Bidmos and Manger (2012) created a new soft tissue correction factor for them (15.86 cm). This new soft tissue correction factor provided accurate results for 75% (with one standard error of estimation) of the specifically Black South African male population group sample (Bidmos & Manger, 2012).

Furthermore, the new correction factors were recalculated in correspondence to actual living height. This was done through the use of Magnetic Resonance Imaging (MRI). This technique is advantageous as the actual living height (stature) of the individual can be measured and used as a comparison for the accuracy of the formulae used to estimate living stature. The living height of each individual was also measured by one researcher, reducing the unwanted introduction of errors by multiple observers. (Bidmos & Manger, 2012). Although the new correction factor by Bidmos & Manger (2012) is considered more accurate for Black South African males, the researchers stated that it needs to be evaluated further (Bidmos & Manger, 2012). This lead Brits and colleagues (2017) to hypothesise that the soft tissue correction factors suggested by Fully (1956) and Raxter and colleagues (2012) may be inappropriate for Black South African females as well (Brits *et al.*,2017).

Brits and colleagues (2017) also used MRI scans to assess the accuracy of the anatomical method for Black South African females. As a result of studying 30 Black South African females it was concluded that universally applied soft tissue correction factors are inappropriate for different populations and sex groups. It was also suggested that the lack of accurate living statures or cadaveric stature may also introduce inaccuracies in terms of estimating stature (Brits *et al*., 2017). In order to better understand the continuous underestimations noticed, they assessed the accuracy of the various soft tissue correction factors for stature estimation in Black South African females.

Brits and colleagues (2017) assessed the accuracy for females and found an underestimation by Fully's (1956) method of 7.9 cm and Raxter and colleague's (2006) revised technique of 6.8 cm. The modified anatomical method from Bidmos and Manger (2012) was also assessed but found to overestimate stature by approximately 7.8 cm. For this reason, Brits and colleagues (2017) deduced new soft tissue correction factors (17.9 cm) for stature estimation in Black South African females (Brits *et al*., 2017).

The above studies tested and called into question the accuracy of the anatomical method, providing support for both population and sex specificity. Therefore the aim of this study was to assess the accuracy of the soft tissue correction factors as described by Fully (1956), Raxter and colleagues (2006), Bidmos & Manger (2012) and Brits and colleagues (2017) in White South African females.

2.2.3. <u>Hybrid method</u>

The anatomical method may be used to create population specific equations used in the mathematical method (Raxter *et al.*, 2006; Ruff *et al.*, 2012; Sládek *et al*., 2012). A limitation to this is that the equations generated from the anatomical method will be specific to either the region or the period (Ruff *et al*., 2012; Pomeroy & Stock, 2012; Mays, 2016). The hybrid method is considered accurate as it uses the anatomical method to estimate stature and then creates mathematical regression equations from the different skeletal elements. Furthermore, the hybrid method is advantageous in terms of the similarity between the reference sample and the individuals being studied, both geographically and temporally.

The hybrid method can be used when trying to calculate the stature of skeletal remains found without additional information on biological factors, such as those from archaeological excavations (Pomeroy & Stock, 2012).

An example of this method is by Jeong and Jantz (2016), who studied 113 complete Korean skeletal remains from the 14^{th} to 20^{th} centuries. They detected that the anatomical method described by Raxter and colleagues (2006) provides accurate stature estimates for this particular population group. The equations created for the estimations of stature from the anatomical method have provided accurate estimates when compared to other techniques that have been, and still are being used in Korea currently, such as those of Trotter and Gleser (1958). It should be noted, however that these equations still need to be validated (Jeong & Jantz, 2016).

2.3. Factors affecting stature

Many researchers, including Pearson (1985) and Trotter and Gleser (1952, 1958) have cautioned against using regression formulae developed from one population for other population. A few publications have attempted to refine the regression equations used. Much of this research has brought about conclusions that the regression formulae used are not accurate as they usually underestimate the stature of individuals when compared to a different population group from their origin (Raxter *et al.* 2006; Bidmos & Manger, 2012). As such, many researchers have focused on generating new equations to improve accuracy for different categorical reasons. The categorical reasons include: sex-specificity, population specificity especially in terms of the geographic area (Muñoz *et al.,*2001; Bidmos & Asala, 2005; Albanese *et al*., 2016), temporal specificity for example of populations found before and after wars (Wilson *et al.*, 2010), population specificity (Trotter & Gleser, 1952; Duyar & Pelin, 2003; Dayal *et al*., 2008), and size specificity to distinguish between short, medium and tall individuals (Steyn & Smith, 2007; Wilson *et al.* 2010; Albanese *et al*., 2016). The categorical reasons have been outlined by various researchers and although they may contribute towards the reason for the equation, some of the researchers did not generate new equations themselves.

2.3.1. Sex

Stature estimation is significantly affected by sex. Sexual dimorphism is an example of how stature may be influenced by an individual's sex. Particularly, males are taller and heavier than females (Hauser *et al.,* 2005; Wells, 2012). Furthermore, these differences may also be influenced by ecological characteristics, both biological and cultural (Wells, 2012; Stulp & Barrett, 2016). Sex specific stature records can provide socioeconomic information. Nourished nations could be considered more dimorphic because males are more influenced by nutritional deficiencies than females (Stulp & Barrett, 2016).

When possible, a sex specific (regression) equation should be used (Ruff *et al.,* 2012). An equation used when sex is unknown does, however, provide valuable information. It should be noted that there is a decrease in female stature when compared to male stature when using a generic equation (Albanese *et al.,* 2016). In response to this, male specific equations should not be used for females, when sex is known and vice versa. This is because often male equations will overestimate female stature and the opposite will take place when using a female equation for males (Albanese *et al.,* 2016). Conversely, these errors are only considered to be minimal (Albanese *et al.,* 2016).

2.3.2. Age

Age is another factor that is important to consider when estimating stature. This is because individual stature declines with an increase in age. According to Trotter and Gleser (1951), this decline starts from the age of 30, whereas Galloway (1988) suggested a decrease from the age of 45. These declining statures have also been deduced to differ sexually. Bidmos and Asala (2005) state that this may not be accurate for all populations as it is based on White American males. Research in some European samples suggest that this loss in stature can start in the early 30s and is similar for both sexes (Cline *et al.,* 1989; Krishan *et al.,* 2012; Niskanen *et al.,* 2013). Additionally, it is quite difficult to detect when stature loss originates. When observing adult stature, the skeletal height of an individual remains stable even when stature has declined with an increase in age (Niskanen *et al.,* 2013; Jeong & Jantz, 2016). Skeletal stature declines at a much later stage than the soft tissue decline. This could be due to vertebral collapse (Jeong & Jantz, 2016).

Age adjustment equations are dependent on the age at which stature starts to decline (Raxter *et al*., 2006). Some researchers also suggest that it may be sex specific (Sorkin *et al*., 1999; Raxter *et al.,* 2006). In total, age related decline in stature is approximately 0.6 cm per decade (Raxter *et al.,* 2006). The age-related stature estimations are based on regression formulae, such as those set out by Trotter and Gleser (1951). These authors suggest an age adjustment of 0.06 cm per year after the age of 30 (Trotter & Glesser, 1951; Ruff *et al.,* 2012; Niskanen *et al.,* 2013). This age-related adjustment is flawed in its applicability as the assumption is that stature decline starts at 30 years and that the decline is linear in males and females. This however, may not always be the case (Niskanen *et al*., 2013). It has been concluded by other researchers that stature declines at a quadratic rate (Cline *et al*., 1989; Sorkin *et al.,* 1999; Raxter *et al.,* 2006; Niskanen *et al.,* 2013), with the curve being steeper in females (Ruff *et al.,* 2012).

It should become regular practice for researchers to adjust for age when calculating stature. If there is no known age for an individual, the maximum stature for that individual should be calculated in order to adjust for age later, when it is known (Niskanen *et al.,* 2013). As previously mentioned, individuals do not often know their own stature nor that of their friends or family (Steyn & Smith, 2007).

2.3.3. Secular trends and population specificity

Secular trends are specifically defined by "the process by which entire populations undergo a change in mean size or shape across generations" (Stulp & Barrett, 2016: 210).

Different population groups require different regression formulae to be derived in order to accurately represent the stature estimation of each respective population group as changes in length of bone and body proportions are evident (Prasad *et al*., 1996; Bidmos & Asala, 2005; Hauser *et al*., 2005; Didia *et al.,* 2009; Mays, 2016). Particular population groups have body proportions that are characteristic of their population (Hanson, 1992). This means that the population being measured needs to be similar to the population used to deduce the formulae (Raxter *et al.,* 2006). In addition, large errors may occur if the stature estimated of an individual is from a population different to that of the reference population (Auerbach & Ruff, 2010) because of the various dimensions of the bones resulting from genetic and environmental changes (Krishan *et al.,* 2012).

Stature is expressed in the genome of individuals. Stature however, is not only predefined by genes, as other influences, such as environmental conditions, health and nutrition of the individual, play an important role too (Shin *et al.*, 2012; Vercellotti *et al.*, 2014; Sládek *et al.*, 2015; Mays, 2016). Furthermore, the development of individuals can be explained better through stature estimations (Sorkin *et al*., 1999). Foetal stature has been influenced by maternal nutrition, and in turn adult stature is influenced by an accumulation of long-term nutrition, especially that of childhood nutrition (Leonard *et al*., 2002; Shin *et al*., 2012; Kurki, 2013). This can thus provide invaluable information on socio-economic status or the bio-cultural environment that different population groups live in (Ruff *et al.*, 2012; Shin *et al.*, 2012; Sládek *et al*., 2015).

The equations used when measuring the tibia to estimate stature in particular, should only be used when the specific population group is known, or an error in stature will be calculated (Sládek *et al*., 2015). This is because of the wide variations observed in tibiae (Sládek *et al.*, 2015). An example of the Holocene European skeletal remains can be used to further explain this. Because of the variations in tibial length between the northern and southern populations, general equations led to an underestimation in the northern population groups. This is because of the lengthening, or shortening, of the distal limbs according to the climate (Ruff *et al.*, 2012). Another reason for the challenging application of stature estimation equations is due to migration patterns. Some body proportions may have been retained, however it is possible that changes may occur. These changes take place in order for individuals to adapt to a new environment. These changes are complex and multifactorial (Ruff *et al.*, 2012; Jeong & Jantz, 2016).

The socioeconomic status of a population is specific to different individuals. An individual’s stature is highly influenced by factors that influence development and growth (Inwood *et al.*, 2015; Sládek *et al*., 2015; Mays, 2016). In turn, trends in stature can allow for historians and economists to interpret the development and welfare of a nation. However this may not be the case for all nations (Inwood *et al.*, 2015; Mays, 2016; Stulp & Barrett, 2016). In general there has been a positive increase in stature for many populations in both developed and developing countries since the 19th century (Stulp & Barrett, 2016) and this is possibly due to an increase in the length of the lower limbs (Myburgh *et al*., 2017). This is congruent with a U-shape curve of stature, particularly in Europe, which may have been brought about due to socioeconomic changes – war, inequality, spread of diseases and trade as well as climate change. The midpoint of this U-shape curve fell between 1450 and 1750 AD which saw male stature decline by approximately 7.6cm (Steckel, 2004; Shin *et al.*, 2012).

The changes that may occur in statures have been observed to be generational changes in population groups in a variety of socioeconomic settings (Sládek *et al.,* 2015; Myburgh *et al*., 2017). For example, more developed countries, such as England and the Netherlands have an increase in average stature due to industrialisation. Dutch men in particular have shown an increase in height by approximately 20 cm from the 18th to the early 20th century (Stulp & Barrett, 2016). It is important to understand the stature trends for the Dutch as they are considered to be strongly linked to White South Africans. It was, however, reported that white South Africans had a lower increase in overall stature than that of the Europeans. This indicates that white South Africans were influenced by various other factors differing to those influencing the stature of Europeans (Henneberg & Van den Berg, 1990; Louw & Henneberg, 1997; Myburgh *et al*., 2017).

Skeletal remains in England show a decline in stature during the medieval period and then a gradual increase in stature from the 19th century (Steckel, 2004). This positive secular trend is comparable to that of some population groups found in developing countries such as the indigenous Evenki in Siberia after the Soviet Union fell (Leonard *et al.*, 2002; Shin *et al.*, 2012). The Evenki have seen a decline in stature, possibly due to general economic decline and isolation of many communities, resulting in a change in lifestyle and changes in nutritional resources (Leonard *et al*., 2002). This is similar to human growth trends as documented in South African history, such as Tobias (1985, 1986) (as cited by Leonard *et al*., 2002). Socioeconomic hardships in South Africa may have led to a negative secular trend (Leonard *et al*., 2002). This is further comparable to the maintaining of an average stature, such as the male stature of rural Mali males, for a century: 1885 to 1985 (Shin *et al*., 2012).

Further example of a minimal stature change or no stature change can be seen in the work by Myburgh and colleagues (2017) where no significantly positive secular trends were witnessed by White South African males and females. It is possible that the lack of stature increases in South Africans when compared to European groups, whom have experienced a significantly positive secular trend, have experienced multiple and complex factors that have influenced their stature. One of these factors may have been poverty during the 1880s and the rise from poverty for White South Africans from the 1930s (Myburgh *et al*., 2017). It is also possible that another factor, such as gene flow from an admixture of genes between different South

African population groups may also have had an effect on White South African stature (Henneberg, 2001).

As previously mentioned, climatic variations may influence secular trends in stature. Climate change influenced a vast change in population groups (Beguelin, 2011). Climate has a very low adjustment rate in terms of stature for humans, and as such it cannot be seen in generational changes (Sládek *et al.,* 2015). According to Bergmann's ecological rules concerning human thermoregulation, an individual that lives in a colder climate will have shorter limbs relative to stature and body mass when compared to an individual who lives in a warmer climate (Kurki, 2013; Sládek *et al.,* 2015; Stulp & Barrett, 2016). This is possibly only true for individuals located in the northern hemisphere, as the southern hemisphere does not have a large enough temperature range to influence thermoregulated stature (Stulp & Barrett, 2016).

It should be noted that although environmental conditions, socioeconomic status and living conditions may have an effect of stature, population specific factors are highly influential in the complexity of secular changes to stature (Henneberg, 2001; Myburgh *et al*., 2017).

2.4. Aims and Objectives

The aim of this study was to assess the accuracy of the anatomical method for stature estimation in White South African females. It was proposed that the soft tissue correction factor that should be used for White South Africans will differ greatly from the original value proposed by Fully (1956). Furthermore, due to population and sex differences the soft tissue correction factors proposed by Raxter and colleagues (2006), Bidmos & Manger (2012) and Brits and colleagues (2017) will also be inadequate for White South Africans. The following objectives were be completed:

1. Assess the correlation between stature and the bone measurements of White South African females.
2. Evaluate the accuracy of the soft tissue correction factors proposed by Fully (1956), Raxter and colleagues (2006), Bidmos & Manger (2012) and Brits and colleagues (2017) for stature estimation in White South African females.
3. Derive a new soft tissue correction factor for the estimation of living stature for White South African females through the use of regression analysis.

3. Methods and Materials

3.1. Participants

There are many different population groups in South Africa. The Black South African population group is the largest, with White South Africans being the second largest population group. This is according to the most recent census (Statistics South Africa, 2016). Work assessing the accuracy of the anatomical method in the Black South African population group has already been completed (Bidmos & Manger, 2012; Brits *et al*., 2017), however, information on the accuracy of the soft tissue correction factors for stature estimation in White South Africans is still lacking.

White South Africans are descended from a combination of European countries, especially the Netherlands, Britain, France, Germany and Portugal (Steyn & Isçan, 1999; Steyn & Smith, 2007). The White South African population is further defined as a unique population group because of temporal changes and admixture and as such they are osteologically distinguishable from their European ancestors (Steyn & Smith, 2007).

Only individuals between 20 and 60 years of age were invited to participate in this study. The younger age limit was selected as all long bone epiphyses are fused by approximately the age of 18 years, marking the end of long bone growth (Scheur & Black 2004). The upper age bracket has been selected because individual stature declines with an increase in age, and according to Cline *et al.* (1989), measurable height changes only take place after the age of 60. The loss in stature takes place due to compression of the intervertebral discs (Raxter *et al*., 2006; Ruff *et al.,* 2012; Niskanen *et al.,* 2013; Jeong & Jantz, 2016), muscles becoming weak, osteoporosis and the deterioration of cartilaginous structures (Cline *et al.,* 1989). The compression of the intervertebral discs can be observed on the anterior midline of the vertebrae (Jeong & Jantz, 2016). For this reason, the changes in the vertebral column are the main contributor to the decline in stature seen with an increase in age (Raxter *et al.,* 2006; Ruff *et al.,* 2012; Niskanen *et al.,* 2013). Raxter and colleagues (2006) concluded that approximately ⅔ of the decline in height is from the soft tissue decline and the last third is from a reduction in skeletal height (Raxter *et al.,* 2006; Jeong & Jantz, 2016).

Previous research by Bidmos and Manger (2012) and Brits and colleagues (2017) showed that there is a very weak correlation between age and estimated stature. It was concluded by Brits and colleagues (2017) that age does not significantly affect the accuracy of stature. For this reason age will not be adjusted for in this research.

An application for ethical clearance for this study was submitted to the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (Clearance certificate number M160628 - Appendix A).

All participants were verbally invited to participate in this research on a voluntary basis. They were informed about the aims of the research and what their participation entailed. Those interested received an information leaflet and informed consent form (Appendix B) for their signatures to partake in the study. Once the consent form was signed, each participant was invited to complete a full body Magnetic Resonance Imaging (MRI) scan. The signing of the informed consent form confirmed that each participant understood the aims of the research and what their participation would entail.

Standard MRI criteria were adhered to (Sutton *et al.,* 2008). Individuals with any metal objects were excluded. Additional exclusion criteria for this research included pregnant and breastfeeding females. If individuals suffered from growth related diseases, nutritional deficiencies or skeletal deformities or abnormalities, including broken bones in the last year that contribute towards their height, they were also excluded. Individuals that are claustrophobic were also excluded. Further exclusion criteria as set out by the Department of Radiology, Wits Donald Gordon Medical Centre, were also included in this research. The exclusion criteria were explained to each participant before they could undergo an MRI scan. They were then each asked to sign the exclusion criteria form from the Radiology Department before any scans could commence.

3.2. <u>MRI scan</u>

MRI scanning was particularly chosen for this research as it provides contrast imagery of the body's internal structures through the emission of minimal iodizing radiation (Bidmos & Manger, 2012; Rathnayaka *et al*., 2012). This is important as it ensured that the use of an image modality was not harmful, as Computed Tomography (CT) scans and X-rays can be (Rathnayaka *et al.,* 2012). The MRI scans were taken using a 1.5 Tesla Phillips Entera MR Scanner, with software version 12.1. T1-weighted survey scans were completed with the use of 6 mm slice thickness for the coronal six stack sequence. The T2-weighted survey was completed with the use of 4 mm sliced thickness for the sagittal four stack sequence. The multistack sequences were fused on a work station with the images saved as a DICOM (Digital Imaging and Communication in Medicine) file.

The MRI scanner produces a strong enough signal of the surrounding tissue of each skeletal element to accurately evaluate the skeletal elements of individuals. This is important to note as MRI would not be the method of choice when assessing skeletal remains for other purposes (Rathnayaka *et al*., 2012). It is relatively easy, although expensive, to acquire the visual data that the MRI scanner retrieves. The storage of the MRI onto a DVD however has allowed for the creation of a digital database. The use of modern image modalities is prompted by the shift in the field of forensic anthropology to move away from physical autopsies to the use of virtual autopsies (Aalders *et* al., 2017; Brits *et al*., 2017). The acquisition of virtual data to create a database are thus necessary to allow for forensic techniques to be created and assessed (Rathnayaka *et al*., 2012; Piva, 2013). Multimedia forensics uses digital evidence, as well as physical evidence, to develop a case. This is done through exploiting the knowledge that classical forensic science provides and applying it to digital images (Piva, 2013). For this research the measurements of the skeletal elements that contribute to stature were collected at the School of Anatomical Sciences, using the image processing software OsiriX (Rosset *et al*., 2004).

A total of forty nine MRI scans in total were completed. Each participant was scanned in the anatomical position after their height, weight and other information was recorded. Each MRI scan took approximately 20 minutes. It should be noted that any MRI scan that could not be accurately read or measured was excluded from this research. This resulted in a total sample size of 44 MRI scans to be analysed.

3.3. <u>Measurements for living stature</u>

Before undergoing the MRI scan, each participant received an information form (Appendix C) to fill in. The information collected included height, weight and possible factors that could affect their height. The height and weight of each participant was measured at the Wits Donald Gordon Medical Centre before the scan was completed. All MRI scans were taken between 8 am and 11.30 am. This is important in order to reduce the diurnal variation of stature (Sjøvold, 2000). Furthermore, it was also important to measure the height, rather than asking the individual their height, as often people do not actually know their exact height (Steyn & Smith, 2007). It should also be noted that often women overestimate their own height (Braziuniene *et* *al*., 2007). A portable stadiometer, which uses a movable headboard was used to measure each participant's height. Each participant was asked to remove their shoes and headgear and stand upright while keeping their head in the Frankfurt Horizontal Plane (Krishan *et al.,* 2012). The participants were asked to relax before their height was measured. The heights were recorded to the nearest 0.1 cm. An electronic scale was used to measure each participant's weight. The weight and height measurements were taken three times and an average between the three measurements was then calculated.

3.4. <u>Measurements taken from the scan:</u>

Skeletal measurements were collected using definitions from Raxter and colleagues (2006). Due to the use of MRI scans, modifications suggested by Bidmos and Manger (2012) and Brits and colleagues (2017) were employed. The left femur, tibia and ankle were measured as per convention (Raxter *et al*., 2006).

Skeletal measurements:

- Skull height: On dry bones this measurement is collected between the basion and bregma of the skull (Raxter *et al.,* 2006). Unfortunately these landmarks cannot clearly be visualised on the MRI scans and therefore this measurement was collected from basion to a point opposite on the ectocranium (Brits *et al.,* 2017). Basion was easily identifiable on MRI scans as the most anterior aspect of the foramen magnum, in a sagittal view, as illustrated in Figure 3.1.
- Height of the second cervical vertebra: The measurement from the odontoid process to the inferior aspect of the axis body was collected along the anterior margin as indicated in Figure 3.1 (Raxter *et al.,* 2006).
- Maximum height of C3 to L5 vertebra: The anterior aspect of each vertebra, from the third cervical to the fifth lumbar vertebrae was measured linearly (Raxter *et al.,* 2006). Examples of the vertebrae, C7, T10, L5 and S1 can be seen in Figure 3.1.
- Height of the first sacral vertebra: The maximum anterior height was measured from the promontory to the inferior aspect of the first sacral vertebra as shown in Figure 3.1 (Raxter *et al.,* 2006).
- Physiological length of the femur: The physiological length of the femur is defined as the length between the most proximal and most distal ends of the femur (Raxter *et al.,*

2006). A line was drawn between the inferior margins of the medial and lateral condyles of the femur. This measurement was collected connecting the midpoint of this line, to the superior aspect of the head of the femur (Bidmos & Manger, 2012). This is indicated in Figure 3.2.

- Length of the tibia: The maximum distance between the lateral condyle and the most inferior aspect of the medial malleolus was collected by drawing a line parallel to the lateral condyle and connecting it to the distal point of the medial malleolus as indicated in Figure 3.3 (Brits *et al.*, 2017).
- Talo-calcaneal height: This is the measurement between the superior aspect of the talus and the inferior aspect of the calcaneal tuberosity. On the MRI scan this measurement was taken in accordance with descriptions by Dayal and colleagues (2008) and Brits and colleagues (2017). As indicated in Figure 3.4, a line was drawn between the calcaneal tuberosity and the distal end of the fifth metatarsal. The talo-calcaneal height was then measured perpendicular to this line from the most superior aspect of the talus.

From the aforementioned measurements, total skeletal height was calculated by summing all the measurements together. Subsequently stature was estimated by adding the appropriate soft tissue correction factors as proposed by Fully (1956), Raxter and colleagues (2006), Bidmos and Manger (2012) and Brits and colleagues (2017).

3.5. Statistics and data analysis

Inter- and intra-observer error was assessed for each skeletal measurement. This was done for approximately 25% of the study as 10 scans were assessed for repeatability. The error was assessed using Lin's (1989) concordance correlation coefficient.

Outliers were detected using the Outlier labelling rule. If any values fell outside of the normal range the participants of these values were explained and then excluded from the sample being studied (Hoaglin *et al*., 1986; Hoaglin & Iglewicz, 1987).

Normality was also evaluated using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Total skeletal height and living stature were also assessed for both outliers and normality. Descriptive statistics including the minimum, maximum, mean and standard deviations were also calculated.

Figure 3.1. Image indicating measurements of the skull and vertebrae. Arrow 1 indicates the skull height measurement, arrow 2 the vertebral height of C2, while arrows 3-6 illustrates the height measurements of C7, T10, L5 and S1 respectively. (Red scale bar = 3.632 cm)

Figure 3.2. Image illustrating the physiological length of the femur. This image indicates the measurement from the superior aspect of the head of the femur to the midpoint of a line drawn between the inferior margins of the medial and lateral condyles (Red scale bar = 3.35 cm)

Figure 3.3. Image indicating the measurement of the tibia length. This image indicates a line drawn parallel to the lateral condyle. This line is then connected perpendicularly to the medial malleolus (Red scale bar = 3.65 cm)

A Pearson's correlation was used to assess the relationship between stature and the long bone measurements as well as the total skeletal height. The r-value indicates the relationship between the variables being compared. The closer the relationship is, the closer the value will be to 1, as the r-value is a number between 0 and 1. The r-squared value indicates the coefficient of determination and will indicate the variability in the regression equation and line of best fit for the model. Paired t-tests were used to assess the accuracy for the stature estimations between living stature and the estimated stature calculated using the soft tissue correction factor of Fully (1956), and the equations suggested by Raxter and colleagues (2006), Bidmos and Manger (2012) and Brits and colleagues (2017).

A regression equation was then calculated for stature estimation of White South African females. The linear regression equation used stature as the dependant variable and the total skeletal height as the independent variable. This was done following suggestions by Raxter and colleagues (2006). The accuracy of this equation was then assessed using total skeletal height from the participant's measurements taken from the MRI scans to estimate living stature. The range of living stature was then indicated through the use of standard error estimates that were both added and subtracted from the living stature.

Figure 3.4. Image indicating how talo-calcaneal height was measured. This image indicates the height measured from the superior aspect of the talus which is measured by connected a line drawn perpendicular to a line drawn between the calcaneal tuberosity and the fifth metatarsal (Red scale bar = 3.43 cm)

4. Results

4.1. Repeatability

Repeatability was measured using Lin's concordance correlation coefficients of reproducibility (Lin, 1989). Table 4.1 indicates the original measurements of the first ten participants were repeated and compared at the beginning of the research (Table 4.1.; 1 vs. 2). As these values were very low, months later, the original measurements were compared to the second repeated measurements (Table 4.1.; 1 vs. 3) and the first and second repeated measurements were compared (Table 4.1.; 2 vs. 3). In order to do this, more time was spent using the programme OsiriX and the measurement definitions were reconsidered. Only measurements with a low repeatability were repeated (skull, vertebrae and talo-calcaneal height). The last ten participants were also repeated (Table 4.1.) four months later in order to assess the repeatability of this research.

From Table 4.1 it is clear that the repeatability of these measurements improved. It should be noted that long bone measurements (femur and tibia) were highly repeatable from the start while vertebrae and skull measurements were initially poorly repeatable. Although the repeatability of these measurements was poor, especially for the vertebrae, the overall total skeletal height was highly repeatable (0.97) indicating that the errors may be minimal.

It can be observed in Table 4.1 that there are open spaces for the femur, tibia (Table 4.1.; 1 vs. 3; 2 vs. 3) and total skeletal height (Table 4.1.; 1 vs. 3; 2 vs. 3; 4; Inter-observer). This is because the measurements were viewed as not necessary to repeat a third time as they showed initial high repeatability.

There was a high repeatability for the last ten participants (Table 4.1.; 4). All of the measurements are higher than 0.9 and thus all the measurements are deemed repeatable (Lin, 1989). These measurements were taken after a lot of practice and familiarity with the use of OsiriX had taken place.

Inter-observer repeatability was completed at the beginning of the research and then again after a few months of practicing and becoming familiar with the use of the OsiriX programme. The inter-observer values recorded in Table 4.1 indicate that many of the skeletal measurements (L5, S1, Femur, Tibia and talo-calcaneal height) are repeatable as they are all higher than 0.9.

While the values for the other skeletal elements (skull, C2, C7 and T10) are not above 0.9, they are all consistently above 0.8.

Table 4.1. Pc values for intra-observer repeatability using Lin's concordance correlation coefficient

	Pc value				
Measurement	Intra-observer (1 vs. 2)	Intra-observer (1 vs. 3)	Intra-observer (2 vs. 3)	Intra-observer (4)	Inter-observer
Skull	0.69	0.79	0.95	0.90	0.87
C2	0.59	0.71	0.86	0.94	0.82
C7	0.53	0.81	0.83	0.92	0.88
T10	0.80	0.86	0.90	0.93	0.82
L5	0.73	0.88	0.94	0.95	0.92
S1	0.85	0.84	0.93	0.90	0.92
Femur	1.00			0.99	0.98
Tibia	1.00			0.99	0.99
Talo-calcaneal height	0.87	0.96	0.91	0.95	0.94

4.2. Outliers and Normality

Outliers were tested for along with normality. Outliers are measured using the median, quartiles and interquartile range. There were no outliers observed in the dataset using the outlier labelling rule (Hoaglin *et al*., 1986; Hoaglin & Iglewicz, 1987).

The sample was also tested for normality using the Shapiro-Wilk test. Normality of total skeletal height and living stature was assessed. All variables were found to be normally distributed ($p>0.05$) (Shapiro & Wilk, 1965).

4.3. Descriptive statistics

The sample consisted of White South African females between the ages of 20 and 60 years with a mean age of 30.14 ± 1.786 years. Approximately 79% of the sample fell within the age range of 20 to 40 years of age. The living stature (LS) of the sample population fell between 152.53 cm and 182.57 cm (mean = 166.43 ± 6.54 cm). The total skeletal height (TSH) of the sample population fell between 140.16 cm and 161.25 cm (mean = 149.22 ± 5.34 cm). The descriptive statistics of the sample has been summarised in Table 4.2.

Table 4.2. Descriptive statistics including the minimum, maximum, mean and standard deviation (SD) for living stature (LS), total skeletal height (TSH), physiological length of the femur and length of the tibia (n = 44)

	Minimum	Maximum	Mean	SD
LS	152.3	182.57	166.43	6.54
TSH	140.16	161.25	149.22	5.34
Femur	41.027	49.288	44.54	2.25
Tibia	32.109	41.907	36.16	2.12

4.4. Correlations

A Pearson correlation coefficient test was used to determine the correlation between living stature and total skeletal height, physiological length of the femur, and length of the femur. A Pearson's correlation coefficient test was also completed to test the relationship between total skeletal height and the physiological length of the femur and length of the tibia.

A statistically significant and strong positive relationship between living stature and total skeletal height ($p < 0.001$; $r = 0.877$). This is visually illustrated in Figure 4.1. It is clear from the scatter plot in Figure 4.2 that there was a statistically significant and strong relationship between living stature and the femur ($p < 0.001$; $r = 0.862$) and the tibia ($p < 0.001$; $r = 0.827$). There was a statistically significant and strong relationship between total skeletal height and the femur ($p < 0.001$; $r = 0.892$) and the tibia ($p < 0.001$; $r = 0.895$) as well. Variability in stature for each of the variables based on the r-squared value accounts for approximately 68.3% - 80.1%. The r-squared values have been presented in Table 4.3.

Table 4.3. Table indicating the correlation coefficients (r and r-squared) indicating the association between Living Stature (LS) and Total Skeletal Height (TSH), Femur (F) and Tibia (T) and TSH and F and T.

	r-value	r-squared value
LS-TSH	0.88	0.77
LS-F	0.86	0.74
LS-T	0.83	0.68
TSH-F	0.89	0.80
TSH-T	0.90	0.80

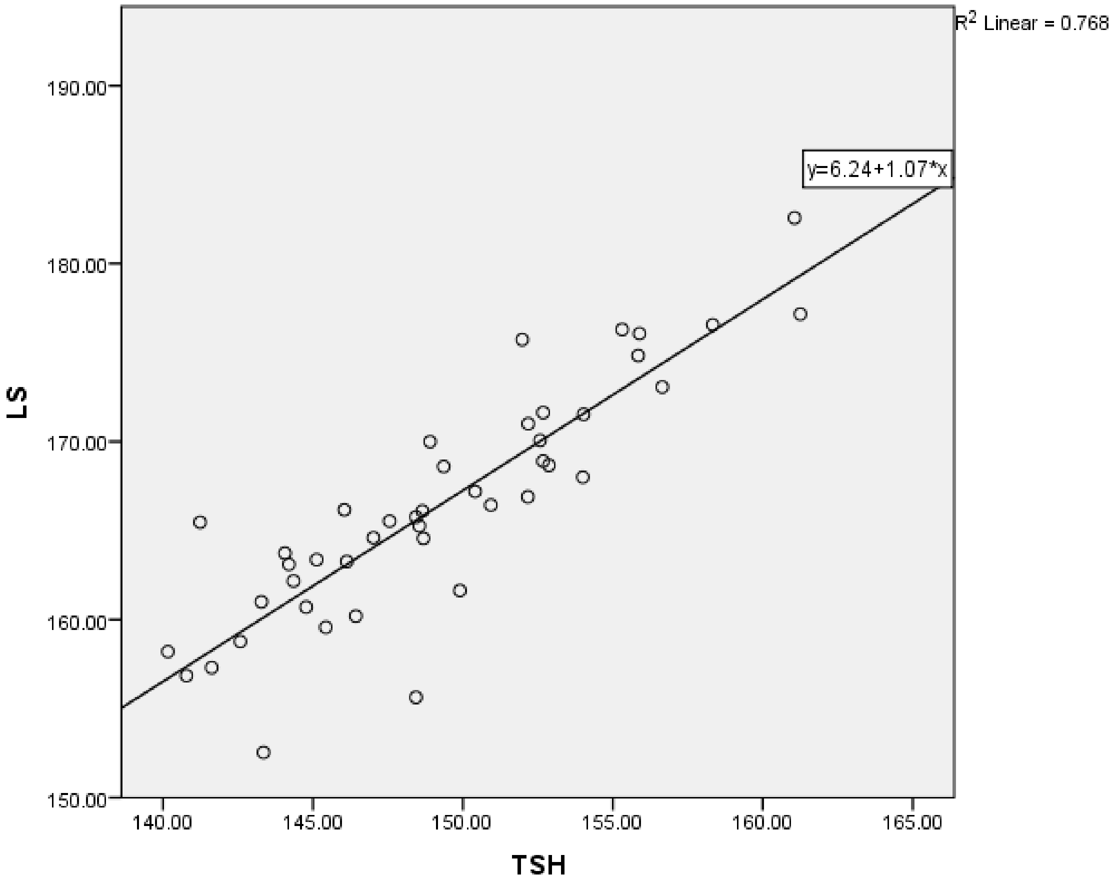

Figure 4.1. Scatter plot indicating the correlation between living stature (LS) and total skeletal height (TSH) ($p < 0.001$; $r = 0.877$)

4.5. Paired t-tests

In order to estimate living stature, total skeletal height was used and added to the appropriate soft tissue correction factors as suggested by Fully (1956), and the equations as suggested by Raxter and colleagues (2006), Bidmos and Manger (2012) and Brits and colleagues (2017). Table 4.4 shows the estimated stature as estimated by each equation.

Fully's (1956) soft tissue correction factors used also significantly underestimated stature on average by 7.1 cm ($p < 0.0001$) according to a paired t-test (Table 4.4). It should be noted that for two participants, DB000145 and DB000147, estimated stature was a result in overestimation by approximately 0.82 cm and 2.8 cm respectively.

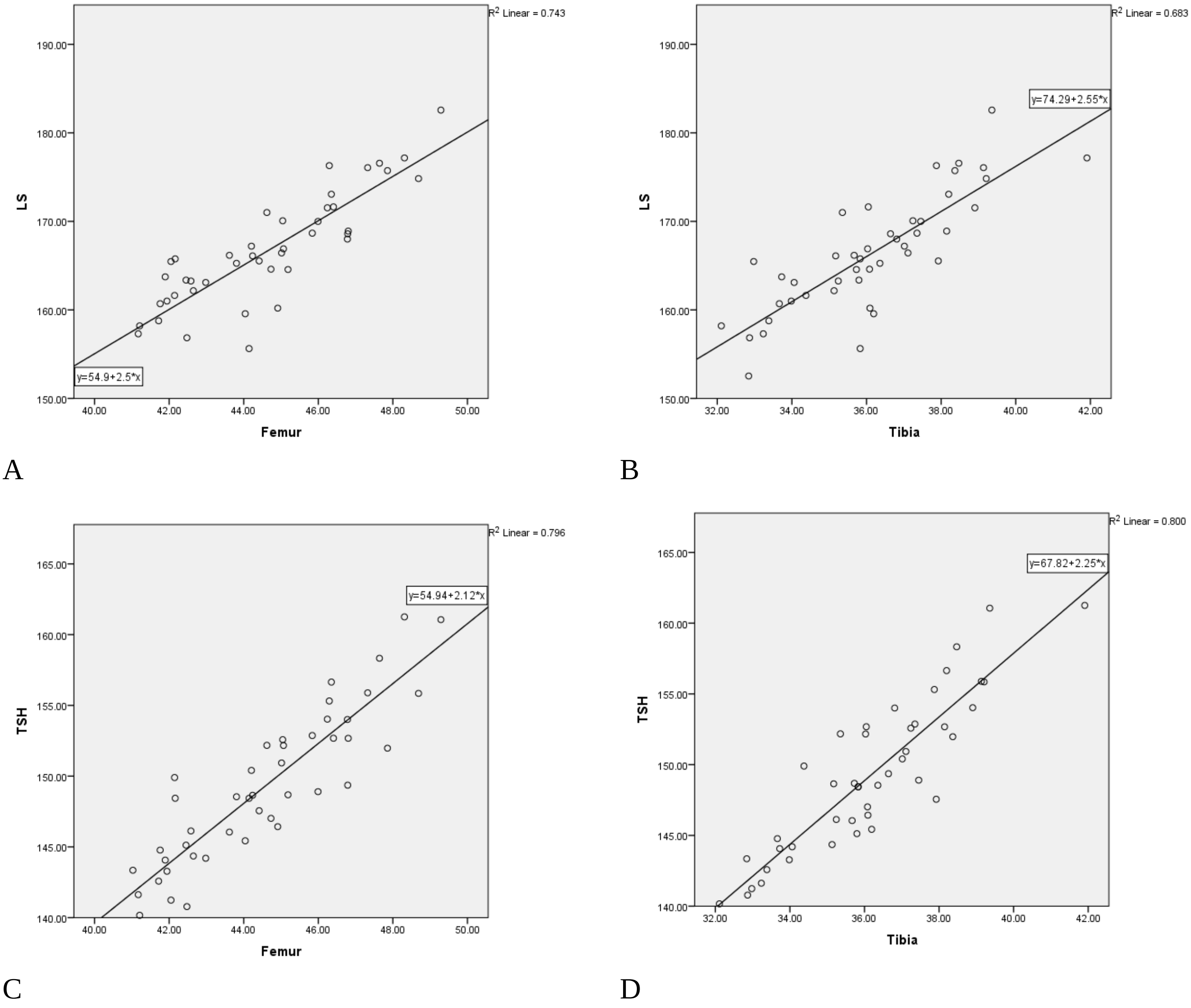

Figure 4.2. Scatter plots indicating the correlations between: A. Living Stature and Femur ($p < 0.001$; $r = 0.862$); B. Living Stature and Tibia ($p < 0.001$; $r = 0.827$); C. Total Skeletal Height and Femur ($p < 0.001$; $r = 0.892$); D. Total Skeletal Height and Tibia ($p < 0.001$; $r = 0.895$)

The paired t-test indicated that Raxter and colleagues' (2006) equation significantly underestimates stature on average by 6.1 cm ($p < 0.0001$) (Table 4.4). It should be noted however that stature was overestimated for the same two participants, DB000145 and DB000147 by 1.94 cm and 3.91 cm respectively.

Bidmos and Manger's (2012) equation significantly overestimates stature by 8.89 cm ($p < 0.0001$) (Table 4.4). All of the participant's estimated stature is overestimated when using this equation.

Brits and colleagues' (2017) equation underestimates stature on average by 0.04 cm ($p<0.929$) however, this underestimation was not statistically significant. As can be seen from Figure 4.4, the line indicating living stature and Brits and colleagues' (2017) equation estimating stature are very close and often mimic each other. The lines for living stature can also be compared to the lines for estimated stature according to Bidmos and Manger (2012) showing overestimation and Fully (1956) and Raxter and colleagues (2006) showing underestimated stature.

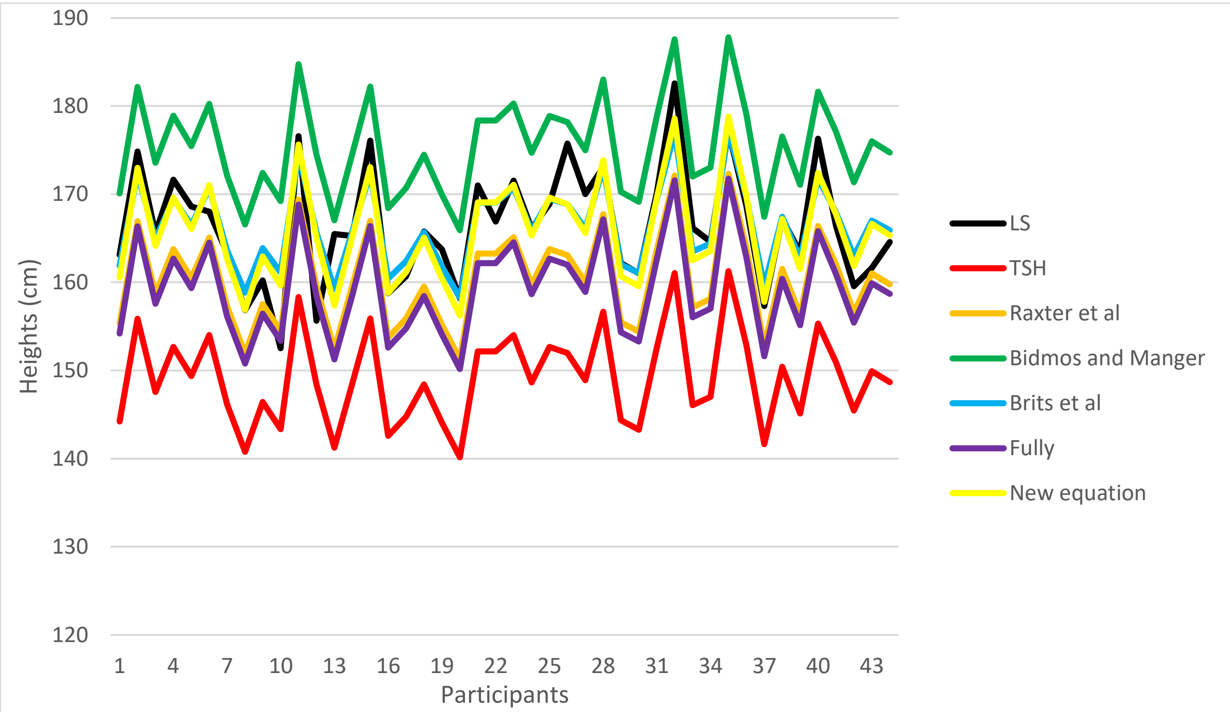

Figure 4.3. Line graph showing the estimation of stature according to work by Fully (1956), Raxter *et al.* (2006), Bidmos and Manger (2012), Brits *et al.* (2017) and the newly generated equation

4.6. New equation for stature estimation

Although Brits (2017) equation was shown to be accurate with a difference of 0.04 cm for stature estimation of White South Africans, a new equation specific for stature estimation for White South African females was generated.

Living stature = 6.24 + TSH * 1.07

SEE = 3.18454

In order to create the above equation, total skeletal height was used in regression analysis. It should be noted that Brits and colleagues (2017) found no correlation between total skeletal height and the soft tissue correction factor, therefore this equation supports the use of a single soft tissue correction factor as opposed to multiple soft tissue correction factors as proposed by Fully (1956).

The regression equation shows a strong statistically significant correlation of $r = 0.877$. This can further be seen in Figure 4.1 where the line of best fit according to the regressed equation, shows a strong, positive linear relationship between total skeletal height and living stature.

The new regression equation was tested by comparing living stature to a range of estimated statures calculated from the total skeletal heights measured for the current study sample. It was determined from adding and subtracting the first standard error of estimate (SEE = 3.18) that 84% of the sample fell within the range allocated. With the use of the second SEE (SEE = 6.37) 95% fell within the range allocated. This therefore shows the accuracy of the new soft tissue equation, where the soft tissue correction factor is 16.69 cm, to be used.

Table 4.4. Estimated stature for each participant according to Fully (1956), Raxter and colleagues (2006), Bidmos and Manger (2012), Brits and colleagues (2017) and the newly generated equation.

Participant	Living stature	TSH	Fully (1956)	Raxter *et al.*, (2006)	Bidmos & Manger (2012)	Brits *et al.*, (2017)	New equation
DB000133	163.10	144.20	154.20	155.32	170.09	161.88	160.53
DB000135	174.83	155.85	166.35	166.92	182.17	172.32	173.00
DB000136	165.53	147.56	157.56	158.66	173.57	164.89	164.12
DB000137	171.63	152.68	162.68	163.77	178.89	169.48	169.60
DB000138	168.60	149.36	159.36	160.46	175.45	166.51	166.06
DB000141	168.00	154.00	164.50	165.08	180.26	170.66	171.02
DB000142	163.27	146.13	156.13	157.24	172.09	163.61	162.60
DB000143	156.85	140.78	140.78	151.92	166.55	158.82	156.88
DB000144	160.20	146.43	146.43	157.54	172.41	163.88	162.92
DB000145	152.53	143.35	153.35	154.48	169.21	161.12	159.63
DB000146	176.57	158.33	168.83	169.40	184.75	174.54	175.65
DB000147	155.63	148.43	158.43	159.54	174.49	165.67	165.06
DB000148	165.47	141.24	151.24	152.37	167.02	159.23	157.36
DB000149	165.27	148.54	158.54	159.65	174.60	165.77	165.18
DB000150	176.07	155.89	166.39	166.97	182.22	172.36	173.04
DB000151	158.77	142.58	152.58	153.71	168.41	160.43	158.80
DB000152	160.70	144.77	154.77	155.89	170.69	162.39	161.15
DB000153	165.77	148.44	158.44	159.54	174.49	165.68	165.07
DB000154	163.73	144.07	154.07	155.19	169.96	161.76	160.39
DB000155	158.20	140.16	150.16	151.30	165.91	158.26	156.21
DB000156	171.00	152.18	162.18	163.27	178.37	169.03	169.07

Table 4.4. Estimated stature for each participant according to Fully (1956), Raxter and colleagues (2006), Bidmos and Manger (2012), Brits and colleagues (2017) and the newly generated equation (continued).

DB000157	166.90	152.17	162.17	163.26	178.36	169.02	169.06
DB000158	171.53	154.03	164.53	165.11	180.28	170.69	171.05
DB000159	166.10	148.65	158.65	159.75	174.71	165.86	165.29
DB000160	168.90	152.67	162.67	163.76	178.88	169.47	169.60
DB000161	175.73	151.98	161.98	163.07	178.16	168.85	168.85
DB000162	170.00	148.90	158.90	160.01	174.97	166.10	165.57
DB000163	173.07	156.65	167.15	167.72	183.00	173.03	173.85
DB000164	162.17	144.35	154.35	155.47	170.25	162.02	160.70
DB000165	161.00	143.28	153.28	154.40	169.14	161.06	159.55
DB000166	170.07	152.58	162.58	163.67	178.78	169.39	169.50
DB000167	182.57	161.06	171.56	172.11	187.58	176.99	178.57
DB000168	166.17	146.05	156.05	157.16	172.01	163.53	162.51
DB000170	164.60	147.02	157.02	158.13	173.01	164.40	163.55
DB000171	177.17	161.25	171.75	172.31	187.78	177.16	178.78
DB000173	168.67	152.87	162.87	163.96	179.08	169.65	169.81
DB000174	157.30	141.62	151.62	152.76	167.42	159.57	157.78
DB000175	167.20	150.41	160.41	161.50	176.53	167.44	167.17
DB000176	163.37	145.12	155.12	156.24	171.05	162.71	161.52
DB000177	176.30	155.31	165.81	166.39	181.62	171.84	172.42
DB000178	166.43	150.93	160.93	162.03	177.08	167.91	167.74
DB000179	159.57	145.43	155.43	156.55	171.37	162.98	161.85
DB000180	161.63	149.90	159.90	161.00	176.01	166.99	166.63
DB000182	164.57	148.68	158.68	159.79	174.74	165.90	165.33
Average	**166.43**	**149.22**	**158.87**	**160.33**	**175.30**	**166.38**	**165.91**

5. Discussion

The aim of this study was to assess the accuracy of the anatomical method for White South African females. Questions raised as to the accuracy of the anatomical method focus on the use of unsuitable soft tissue correction factors (Raxter *et al.*, 2006; Bidmos & Manger, 2012; Brits *et al*., 2017). It is important that the soft tissue correction factor is addressed and the accuracy is assessed as the anatomical method is considered to be the most accurate method in attempting to estimate height from skeletal remains (Bidmos, 2005; Maijanen, 2009).

5.1. Virtual Anthropology and MRI scans

The use of computers has allowed anthropologists to analyse anthropological objects, such as bone, three-dimensionally and internally. This is known as “Virtual Anthropology” (Weber *et al*., 1998). Virtual anthropology is a new method of studying skeletal remains without damaging the bones themselves in order to gain quantitative and qualitative data. This is especially helpful when a traditional anthropological approach cannot be used. Virtual anthropology also allows for the manipulation of information, such as segmentation, which is not possible with a physical bone itself (Weber *et al.,* 1998; Weber *et al*., 2001; Benazzi *et al*., 2010). There are many other implications for the use of virtual anthropology, including facial reconstruction and clinical uses in terms of planning and simulating operations (Weber *et al*., 2001).

MRI scans allow for the study of living individuals without exposing participants to any harmful ionizing radiation (Thorpe, 2008). MRI scans can thus contribute to the safe gathering of a digital database of human skeletal remains. Creating a virtual database allows for permanent virtual copies that can be used for a variety of different research topics (Weber, 2014). There is an increase in the use of digital skeletal remains to assess the accuracy of various methods used in the identification of unknown individuals as many skeletal collections no longer represent the current population groups. This is because of secular trends (Bidmos & Asala, 2005; Wilson *et al*., 2010; Vercellotti *et al.*, 2014; Stulp & Barret, 2016).

5.2. Repeatability

An approximate 0.1 - 0.17 increase in the Pc-values indicates that there was an improvement in the precision of measuring the skeletal elements over the course of this study. It is possible that the initially poor results were because of the misinterpretation of the measurement definitions and the incorrect identification of the basion and a vertically opposite point. It is possible that the point on the ectocranium was not always taken exactly vertically and the measurement may have slanted to the side of the possible point where the bregma is estimated to be. The results improved over time in this research as a greater understanding of the measurement definition took place and practice in identifying the elements took place, and the development of expertise in the use of OsiriX took place (Pajkrt *et al.,* 2000).

Furthermore, the intra-observer repeatability measurements recorded for the last ten participants (Table 4.1.; 4) have values greater than 0.9, indicating that this research is repeatable (Lin, 1989).

All measurements that contributed towards the assessing of the accuracy of the anatomical method were taken by one observer. This is important in order to avoid inter-observer errors when measuring, which is often a problem in research (Ousley, 1995).

The intra-observer repeatability shows a higher Pc value than the inter-observer repeatability generally. The inter-observer repeatability measurements are mainly above 0.9. The values that range between 0.8 and 0.89 may be due to the presence of osteophytes on the vertebrae, which could result in distortion of the superior and inferior vertebral margins (Brits *et al.*, 2017). The strength of the correlation can be seen by the 68.3 – 80.1% of the variability presented by the measurements, according to the r-squared values.

5.3. Measurements

Raxter and colleagues (2006) redefined the measurements used by Fully (1956) for the anatomical method. Their measurements were used in this research with corrections as suggested by Bidmos and Manger (2012) and Brits and colleagues (2017).

With the use of MRI, Bidmos and Manger (2012) encountered some difficulties with some of the measurements described by Fully (1956), such as with the skull height, vertebral height and the height of the articulated talus and calcaneus. This is because the measurements for dry skeletal remains are not always a possibility on virtual images of the skeleton. Furthermore, the skeletal points cannot be located on either the sagittal or coronal MRI scans. For example, the measurement of the skull height is meant to be taken between the basion and bregma, however the bregma cannot be seen on the MRI scans. Therefore the skull height was measured between the basion and a point vertically opposite on the ectocranium (Brits *et al*., 2017). These were regarded as minor limitations by Bidmos and Manger (2012) as new definitions of measurements could be reconstructed. Although definitions have been adapted for MRI use, the applicability thereof when applied to skeletal remains needs to be tested. As such, the newly proposed equation and soft tissue correction factor should be validated on a skeletal sample first, before introducing it into standard practise.

It is possible that many of the definitions put forward by Fully (1956) were misinterpreted by various researchers, which has resulted in the need for researchers to put forward precise definitions (Raxter *et al*., 2006; Maijanen, 2009). It is therefore suggested that better definitions need to be developed and used when conducting research on virtual images, much like the skeletal element measurements contributing to stature described by Raxter and colleagues (2006). These measurements will need to be tested first before they can be implemented.

An example of where Fully's (1956) technique was inadequately described includes the different interpretations when taking measurements of the maximum vertebral height (Raxter *et al.*, 2006). Fully (1956) does not explain how or where exactly he measured the maximum vertebral height, which has resulted in various interpretations by researchers (Maijanen, 2009). Due to the different interpretations of measurement techniques, such as Lundy's (1985) description to measure along the midline, without mention of "maximum", which is the instruction of Fully (1956), Raxter and colleagues (2006) followed a technique that allowed for the closest correspondence to living stature (Lundy, 1985; Raxter *et al*., 2006).

The problems associated with measuring vertebrae are highlighted by the repeatability values of these bones, as they were lower than other measurements. Although these values increased with later measurements, the values were still often lower than those of the long bones (femur and tibia), skull and ankle. Often there can be no difference observed between the vertebrae and the intervertebral disks when using the MRI scans. This makes it difficult to discern which elements are soft tissue compared to which elements are skeletal on the virtual images.

5.4. Descriptive statistics

The female living statures ranged between 152.53 cm and 182.57 cm (n = 44) (mean = 166.43 ± 6.54 cm). These recorded living statures can be compared to that of white South African female military records, which indicate the average height of White South African females is 160.08 cm (± 6.08 cm). The average height of White South African females recorded in the current study was also slightly greater than that reported by Steyn and Smith (2007) for this population group.

Figure 4.2 indicates that there was a strong positive correlation between living stature and femur and tibia measurements as well as total skeletal height and the long bone measurements. The strong correlation may be because the lower limb long bones (femur and tibia) are the main contributing factors to stature (Bidmos & Manger, 2012; Brits *et al*., 2017). The strongest correlation was between total skeletal height and living stature (r = 0.877). This is due to the fact that the skeletal elements contributing to total skeletal height have a direct contribution to living stature (Raxter *et al*., 2006; Maijanen, 2009).

5.5. Accuracy of the soft tissue correction factor

The results indicated that stature estimated by the Fully (1956) and Raxter and colleagues (2006) equations significantly underestimated stature while the stature equation used by Bidmos and Manger (2012) significantly overestimated stature. The soft tissue correction factors (STCF) from Fully (1956) (TSH </= 153.5 cm, STCF = 10 cm; TSH between 153.6 cm and 165.4cm, STCF = 10.5 cm; TSH >/= 165.5 cm, STCF = 11.5 cm), Raxter and colleagues (2006) (STCF = 12.4 cm), Bidmos and Manger (2012) (STCF = 25.86 cm) and Brits (2017) (STCF = 17.9 cm) differ from the current study (STCF = 16.69 cm).

King (2004), Bidmos (2005) and Raxter and colleagues (2006) observed that Fully's (1956) method underestimated stature for their samples when assessing the accuracy of the soft tissue correction factor. Previous research underestimations were of smaller magnitudes, including King (2004) with 2.4 cm, Bidmos (2005) with 2.4 cm and Raxter and colleagues (2006) with 4.3 cm, compared to the current study which found a 7.1 cm underestimation of stature when using Fully's (1956) method. Brits and colleagues (2017) observed similar underestimations by Fully's (1956) method of 7.9 cm. The underestimation of the current study was however smaller than the underestimation noticed by Bidmos and Manger (2012) which was 15.8 cm difference.

There was an underestimation of stature by 6.1 cm using Raxter and colleague's (2006) soft tissue correction factor. This underestimation is possibly due to the different population groups being used, as the Raxter and colleagues (2006) study was based on American males and females. It should be noted that Raxter and colleagues (2006) created two equations for estimating living stature. The equation used in this research was without the age correction term. It is also possible that this underestimation was due to secular trends.

Bidmos and Manger's (2012) method for estimating stature overestimated stature in the current study by 8.89 cm. The overestimation of stature is in accordance with Brits and colleagues (2017), who also observed an overestimation in stature by Bidmos and Manger (2012) by an average of 7.8 cm. This could be due to differences in sex as Bidmos and Manger (2012) studied male participants while Brits and colleagues (2017) studied female participants. Males in general are consider taller and heavier than females (Hauser *et al.*, 2005; Wells, 2012). In addition, inaccuracies may have been due to the modification of the measurements (tibia and talo-calcaneal height) used by Brits and colleagues (2017) and the current study compared to those of Bidmos and Manger (2012) (Brits *et* al., 2017).

The Brits et al. (2017) method to estimate stature showed no significant difference in estimated stature for the current sample. The results of the current study indicated that there was an average of 0.04 cm underestimation in stature. Thus, it can be concluded that the soft tissue correction factor put forward by Brits and colleagues (2017) is also accurate for White South African females. It is possible that both Black and White females have been exposed to similar climatic variables which may explain why they do not differ greatly in stature (Beguelin, 2011; Sládek *et al*., 2015). Alternatively it could be possible that female variations in height are not as diverse as male variations, as were noted by Bidmos (2005) and Bidmos and Manger (2012).

Although the Brits and colleagues (2017) equation was observed to accurately estimate stature for White South African females, a new equation was generated in an attempt to improve the accuracy of stature estimation for White South African females.

5.6. New equation for stature estimation

As has been ascertained from this research, previous equations for estimating stature for White South Africans yielded inaccurate results. As has been previously discussed the Bidmos and Manger (2012) equation overestimated stature, while Fully's (1956) soft tissue correction factor and Raxter and colleagues' (2006) equations underestimated stature. Thus, in order to improve the accuracy for stature estimation a new equation was generated specifically for White South African females.

The new regression equation indicates a strong positive linear correlation ($r = 0.877$; r-squared $= 0.769$) however, it does not provide as strong a correlation as Raxter and colleagues' (2006) correlation ($r = 0.952$), Bidmos and Manger's (2012) correlation ($r = 0.934$), or Brits and colleagues (2017) correlation ($r = 0.942$). Furthermore, the standard error of the estimate was also greater (SEE = 3.18 cm) than that of Raxter and colleagues (2012) (SEE = 2.31 cm), Bidmos and Manger (2006) (SEE = 1.93 cm) and Brits and colleagues (2017) (SEE = 1.8 cm). Although there are differences in correlation ($r = 0.877$) as well as the SEE (3.18), 94% of the sample fell within two standard errors of the estimate. This further confirms the accuracy of the newly proposed equation.

5.7. Limitations

Recruiting volunteers was often challenging. When participants were recruited, some became anxious and could not complete the scan successfully. This has been noticed in other MRI patients where the patient may feel panic, anxiety and fear of restriction or suffocation when undergoing an MRI scan (Thorpe *et al*., 2008).

Due to technical problems, some individuals also had to be excluded as there were skeletal elements missing from the MRI scan recorded (feet and vertebral column). Sometimes the quality of the MRI scan was not of a high resolution. This sometimes made it difficult to ascertain the skeletal points to be used to collect measurements. It is important when using digital images, to practice. In order to collect accurate measurements, it is important that the skill and expertise required for this research is acquired over time. Although 44 participants are a large enough sample to develop a new regression equation for stature estimation, it is possible that a larger sample size may increase the accuracy of the equation and the soft tissue correction factor.

Furthermore, it is unclear how accurate the equations derived from MRI scans preform and dry bone and as such future efforts, exploring the validity of this methods are required.

6. Conclusion

The aim of this research was to assess the accuracy of the anatomical method for stature estimation by assessing the accuracy of the soft tissue correction factors used in estimating stature. Previous research has shown that the soft tissue correction factors have been problematic and have resulted in the underestimation and overestimation of stature. The current research used Magnetic Resonance Imaging (MRI) scans to assess the accuracy of the soft tissue correction factor used for stature estimation in White South African females. The results of the current research indicated that the various stature estimation methods are inaccurate because of the inappropriate soft tissue correction factors used for White South African females. This is excluding the Brits and colleagues (2017) soft tissue correction factor that can be used as it shows a negligible difference in height of an average 0.04 cm underestimation in stature. Although the Brits and colleagues (2017) anatomical method is considered to be accurate, a new equation was generated in order to attempt to increase the accuracy for stature estimation of White South African females.

It can thus be concluded that either the Brits and colleagues (2017) equation or the newly generated equation can be used for White South African females in order to estimate stature accurately.

Future research based on this study can include a validation study between dry bone and the MRI data collected in order to access the applicability and accuracy of the newly generated equation.

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APPENDIX A

Human Research Ethics Committee (Medical) - Clearance Certificate M160628

R14/49 Miss Michelle Heather Cloete

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160628

NAME:
(Principal Investigator) Miss Michelle Heather Cloete

DEPARTMENT: School of Anatomical Sciences
Wits Donald Gordon Medical Centre

PROJECT TITLE: Stature Estimation in White South Africans

DATE CONSIDERED: 24/06/2016

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Mrs Desire Britz

APPROVED BY: Professor P Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 28/10/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.** The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in June and will therefore be due in the month of June each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date 01/11/2016

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX B

Information leaflet and consent form for participants

School of Anatomical Sciences
University of the Witwatersrand, Johannesburg
7 York Rd, Parktown, 2193, South Africa • Tel: +27 11 717 2713 • Fax: +27 11 717 2422 • www.wits.ac.za

INFORMATION LEAFLET AND INFORMED CONSENT

Good day. My name is Michelle Cloete. I am a Masters student in the School of Anatomical Sciences at the University of the Witwatersrand, Johannesburg. My research is about estimating the height in individuals from their bones. I would like to use Magnetic Resonance Imaging (MRI) scans of healthy individuals in older to develop the accurate methods for stature estimation specific to white South African adults.

Your involvement

I would like to invite you to volunteer to have a full body MRI scan taken at the Wits-Donald Gordon Medical Centre. The entire process should take no more than one hour. You will be asked to change into a theatre gown, after which your height and weight will be measured. You will then be asked to lie as still as is possible in the MRI scan. The scan takes approximately 20 minutes. Once the MRI scan has been completed the images will be saved on a disc and reconstructed on a computer at the School of Anatomical Sciences so that bone measurements can be taken.

Please read the following statements before considering to participate:

1. You will be required to fill in the medical form attached. It is important to know and understand your medical and surgical history before you can qualify for this study.
2. Please be open with us regarding your health history to ensure no harm is done to you.
3. Information pertaining to your gender (sex), age and handedness (the dominant hand) will also be asked for. All your personal information will be kept confidential. You will remain anonymous in the study.
4. You will be asked to sign a confirmation of your understanding of the study, of which you will also receive a copy.
5. You will be asked to complete an indemnity form.
6. You will not receive a copy of your MRI scan, nor will you be allowed to see it. Furthermore, we are not at liberty to discuss your MRI scan with you.
7. Please only participate in this study if you are satisfied and comfortable with all the procedures involved.
8. Please do not hesitate to ask any further questions of this study to either myself, or my supervisor.

Will discomfort or inconvenience be experienced during the MRI scans?

Magnetic Resonance Imaging (MRI) is dissimilar to both X-ray and CT scans, in that there are no known side-effects. MRI does not use ionizing radiation. Research has however found that any implants, such as pacemakers, cochlear implants or metal rods for broken bones, may cause discomfort. This is because the MRI machine creates a magnetic field with strong static and radiofrequency energy to create the images. Thus, the implants may either move or heat up and as such individuals with metal implants cannot participate in this study. Please note that this may also take place with jewellery. The

MRI machine is noisy and for this reason earplugs/earphones will be provided with some background music. You are also required to lie as still as possible during to scan. The bore of the MRI machine is a small, confined space and individuals suffering from claustrophobia (which is the fear of enclosed spaces) should not participate.
The qualified and experienced staff from the Department of Radiology at Wits Donald Gordon Medical Centre will perform all the scans.
Please note that due to high patient loads at the Wits Donald Gordon Medical Centre, the MRI scanning process may be delayed. For this reason, you may need to wait before you can be scanned. Alternatively, your appointment may be rescheduled.

Benefits and rights of this study

You will not directly benefit from partaking in this study. However, your participation in this study will benefit the field of Forensic Science in South Africa.
Please note that you may at any point, without reason, withdraw from participation in this study as your participation is completely voluntary. We do however, reserve the right to withdraw you from participation in this study, at any point.
Please note that a radiologist will not be interpreting the MRI scans and as such if any abnormalities occur they will not be picked up.

Exclusion criteria

There are various exclusion criteria that need to be met in the interest of your health and safety if you decide to participate in this study.

- You may not be pregnant or breastfeeding during the MRI scan. Please sign the supplementary Informed Consent for Women of Childbearing Potential provided at the end of this document. This is because the side-effects on a foetus are unknown.
- You may not participate if you have answered yes to any of the questions on the Wits Donald Gordon Medical Centre MRI exclusion criteria list.
- You may not participate if you have suffered from any nutritional diseases (such as kwashiorkor – a protein deficiency), bone diseases or taken medication, such as cortisone during growth that may have stunted or progressed your height.
- You may not participate if you have broken any bones in the last year.
- Please do not participate if you think you may or if you do suffer from claustrophobia (fear of small spaces)

Financial arrangements

There will be no financial costs to you to participate in this study nor will you receive any financially remuneration for your participation in this study.

Ethical approval

An application for ethical clearance has been approved by the Human Research Ethics Committee – Medical (Clearance certificate number: M160628) at the University of the Witwatersrand. If you want any information regarding your rights as a research participant, or have any complaints regarding this study, you may contact Prof. Cleaton-Jones, the Chairperson of the University of the Witwatersrand, Human Research Ethics Committee (HREC), which is an independent committee established to help protect the rights of research participants at (011) 717 2301.

Confidentiality

All information, including personal and research data collected during this study will remain confidential and each participant will remain anonymous in this study. Please note that all information

collected in this study may further be used in publications in scientific journals or reports given at scientific conferences. No information will be included that can identify you. Your signature of confirmation authorizes us to release your information to the respective authorities.
All MRI scans will be stored at the School of Anatomical Sciences at the University of the Witwatersrand. Furthermore, subject to the Human Research Ethics Committee (HREC, Medical), the MRI scans taken in this study may be used for future research.

Please contact me if you have any questions or require additional information
Michelle Cloete: 0798154971 or 670803@students.wits.ac.za
Alternatively, please contact Desiré Brits at 011 717 2304 or desire.brits@wits.ac.za

Consent Form:

I hereby confirm that I, ____________________________, have been informed by the investigator, Michelle Cloete, about the nature, conduct and risks of the study.
I have received, read and understood the provided information of the study and the possible risks and benefits of the study. I understand the exclusion criteria of participating in this study and I confirm that they do not apply to me.
I understand that all my information collected during this study, including my age, sex, weight, height, handedness and the MRI scan will be used anonymously in this study and possibly in future research.
I understand that I will not receive a copy of my MRI scan and that the researcher will not discuss my MRI scan with me.
I understand that I may withdraw my participation from this study, without reason, at any point. I also understand that I may be withdrawn from the study at any point, without reason. I have had sufficient time to ask questions as well as do further research on my own if needed.
I am completely willing to participate in the study through the use of MRI scans. I understand that I will receive a copy of this consent form.

Name and Surname Date and Time

____

Signature

Supplementary Informed Consent for Women of Childbearing Potential:

I, ____, understand that I may not participate in this study if I am pregnant or breastfeeding. I thus, confirm that I am not pregnant, nor am I breastfeeding.
I have had sufficient time to ask questions as well as do further research on my own if needed.
I am completely willing to volunteer to participate in the study through the use of MRI scans. I understand that I will receive a copy of this consent form.

Name and Surname Date and Time

____

Signature

APPENDIX C

Participant Questionnaire

PARTICIPANT INFORMATION SHEET

Age: ____________________ Sex (X): [M] [F]

Height: ______________________ Weight: ____________________

Handedness (X): [Left handed] [Right handed]

There are a number of factors that can interfere with the reliability of this study. Please tick the appropriate box (X) and describe where applicable:

Have you ever suffered from any nutritional diseases? [Y] [N]

Describe: ____

Have you ever suffered from any growth related diseases? [Y] [N]

Describe: ____

Do you have any skeletal abnormalities? [Y] [N]

Describe: ____

Have you ever broken any bones? [Y] [N]

Which bones? ____

When: ____

Did you say yes to any of the questions on the form provided by Donald Gordon Medical Centre? [Y] [N]

Describe: ____

Do you participate in any sports? [Y] [N]

Describe: ____

Would you like to be informed of any <u>suspected</u> irregularities? [Y] [N]

Date: ____________________

APPENDIX D

Turn-it-in Report

turnitin

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

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Assignment title:	MScMed Turnitin
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Page count:	65
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Anatomical Sciences

Stature Estimation in White South African Females

By

Michelle Cloete

2017

670803:Final_MSc_draft_-_Michelle_Cloete.pdf

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to University of Witwatersrand Student Paper	5%
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"Exploring the multidimensionality of stature